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Towards a terahertz driven ultrafast electron source

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Terahertz (THz)-driven electron acceleration have recently emerged [3–5] as a promising approach for developing compact accelerators. The millimeter scale of THz-based accelerators offers an unexplored compromise between the meter scale of existing RF devices and the micron scale of other laser-based compact accelerator technologies, such as dielectric laser accelerators (DLAs) [1] and laser-plasma accelerators [2].

Here we discuss a few key components we have developed for THz-driven electron accelerator. First of all, a Segmented Terahertz electron accelerator and manipulator (STEAM) setup was developed that is capable of performing multiple high-field operations on the six-dimensional phase space of ultrashort electron bunches [2]. Figure 1(a) shows the STEAM structure composed of arrays of parallel plate waveguides with dielectric fillings to delay the THz pulses in each waveguide, such that when excited with high energy THz pulse jointly, a tilted pulse front is created at the interaction point with electrons. This leads to continuous acceleration of the electron bunch in the interaction areas. To demonstrate this concept, we used a UV-photo-triggered, 55 kV DC-gun to inject electron bunches into the accelerating structure. The accelerating structure is driven by two single-cycle THz pulses. For acceleration, the two THz pulses are injected such that the electric fields constructively interfere in the center of the structure in the forward direction. The transvers magnetic fields are canceled. 70 keV electron acceleration has been achieved. If the pulses are delayed with respect to each other by half a THz wavelength, the electric fields cancel in the center of the device and the transvers magnetic fields add, which leads to a transvers deflection of the electron bunch. This operation mode can be used for streaking of the electron bunch to measure its duration with sub-10 femtosecond resolution. The structure has been also used to demonstrate temporal pulse compression to sub-100 fs, focussing with up to 2 kT/m focussing strength.

Second, in order to extend this THz-driven electron acceleration to the multi-MeV range, an investigation of approaches supporting longer interaction lengths and more effective interaction is needed. Here, we demonstrate first steps in electron acceleration and manipulation using dielectrically lined waveguides powered by temporally long, narrow-band, multicycle THz pulses that copropagate with the electrons (Fig. 1b). This geometry offers centimeter-scale single-stage interaction lengths and offers the opportunity to further increase interaction lengths by cascading acceleration stages that recycle the THz energy and rephase the interaction. We prove the feasibility of THz-energy recycling for the first time by demonstrating acceleration, compression, and focusing in two sequential dielectric capillary stages powered by the same multicycle THz pulse. Since the multicycle THz energy achievable using laser-based sources is currently a limiting factor for the maximum electron acceleration, recycling the THz pulses provides a key factor for reaching relativistic energies with existing sources and paves the way for applications in future ultrafast electron diffraction and free-electron lasers.

References
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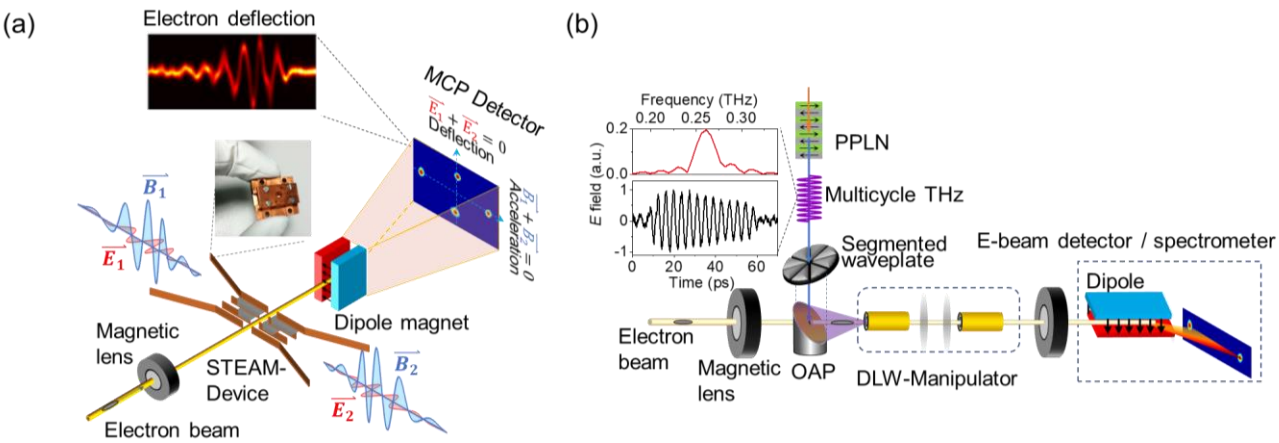

Figure 1. Segmented THz electron accelerator and manipulator (STEAM) powered with single-cycle THz (left) and DLW based THz Linac powered by multi-cycle THz.